



# Hibernacula Manipulation Project

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## Background and Vision:

The Michigan Technological University's (MTU) College of Forest Resources and Environmental Science (CFRES) in partnership with the Michigan Department of Natural Resources (MDNR) are developing an experiment focused on mitigating the deleterious effects of white-nose syndrome on bats in abandoned mine hibernacula. Specifically, CFRES and MDNR aim to lower the temperature within mines to reduce the growth rates of the fungus responsible for white-nose syndrome while maintaining temperatures adequate for bat hibernation. The focus of this project is to develop a system to assist the implementation of the experiment by conditioning and pumping in external air to achieve the desired temperature. An aerial view of the mine shaft point cloud is shown below. The experimental area is bounded on the south side by a natural rock pile. The north side is currently unbounded. The south end splits into three shafts, all dead-end in under 500 feet.

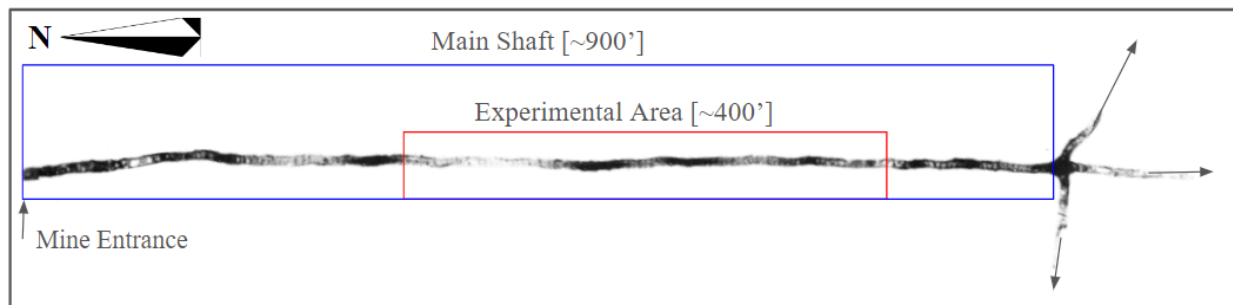


Figure 1: Overview of the Mead Mine Experimental Area

## Design Developments:

### *I. Power Generation*

#### *I.I. Internal Investigation*

The Open Source Hardware Enterprise (OSHE) Team determined the viability of solar power through custom test set-ups at the Mead Mine and consulting Bay Electric renewable energy experts. The OSHE project team erected two solar test units to test two locations and two angles for solar energy production. The location of the two test units, as well as the units, are pictured below. The test units were erected in November and the energy production test was conducted in February.



Figure 2: Test Unit Locations



Figure 3: Test Unit 1



Figure 4: Test Unit 2

A custom data acquisition system (DAQ) was then designed and implemented to collect data on the power generated. The schematic and an image of one of the units are located in the Appendix. Unfortunately, Test Unit 1's DAQs failed, so data was only collected and analyzed for Test Unit 2. Figure 5 below shows the power collected by the two solar panels in terms of efficiency. This is the longest stretch that the panel operated, 12 days. From the data collected, it is expected that the maximum power expected in February is ~20% of panel capacity. It was observed while the test units were standing that

minimal snow was acquired on either panel, angled, or vertical. This was a concern due to the snowfall this location typically receives.

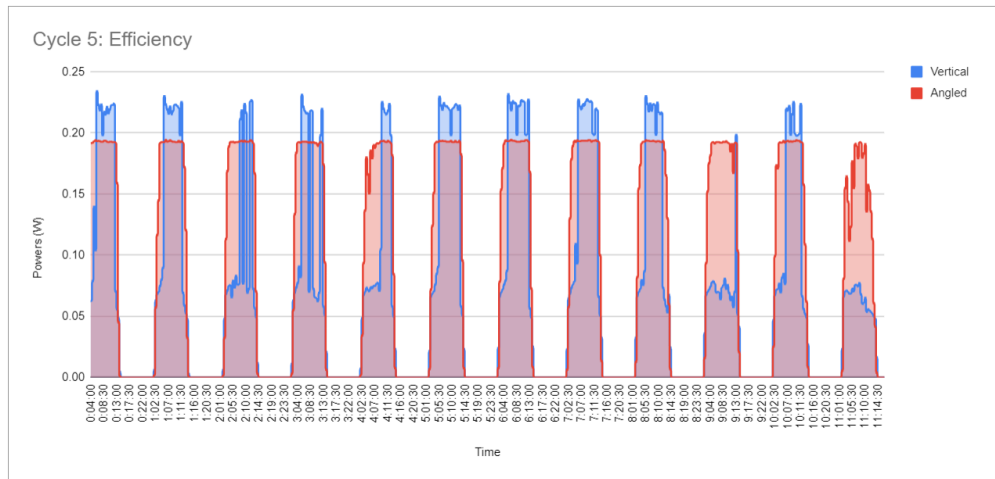


Figure 5: Solar Panel Efficiency

### I.II. Bay Electric Proposal

Bay Electric proposed three solutions:

1. Solar array at Location 1
2. Liquid propane (LP) Generator above the Mead Mine entrance (See Figure 6)
3. A combination of the two above options

Using a solar pathfinder, it was determined that Location 2 was not a viable option for a solar array because of the shadows of the Porcupine Mountain (in which the Mead Mine is located). For the entirety of December, Location 2 is in the mountain's shadow for the entire day, thus essentially no power would be generated. This is not acceptable as the fan needs to run in December, and was missed by the OSHE project team due to testing in February. Fortunately, Location 1 is far enough from the mountain that it is not shaded in December. The cable from the array will need to be run over the road and into the mine, as boring under the road puts the project over budget. A battery pack of 8 batteries would be located approximately 10 feet into the mine. The array will be composed of eight 480 watt bifacial solar modules mounted on an array at a fixed tilt of 80 degrees. This number of panels accounts for 10% efficiency which can be expected in the winter months. The array will be fixed because in this configuration it will only be used in the winter, for which there is one ideal angle. This does limit the array for the future if a need arises in the summer.

An LP generator was suggested as an alternative to the solar array. A generator's power is independent of shadows, thus it could be located on the South side of the road. This means that no cables would be run across the road, which is beneficial because this system will potentially be used in the summer for additional testing. The generator would work with the same battery pack as the solar array, and would automatically start once the batteries reach 50% capacity. An LP tank would need to be installed in conjunction with the generator and would be located adjacent to the generator itself. This cost is not included in the quote below. If this option is deemed the most viable, more consideration needs to be

given to the vibration caused by the generator and the potential effects on the bat's hibernation being located this close to the mine.



Figure 6: Proposed Generator Location

The third proposal was a system that uses a solar array and a generator. This is the best long-term option. However, with the future of this project being questionable, the OSHE team does not recommend pursuing this option, as it is the most expensive option. If the experiment in the winter of 2024/25 goes well, this option should be revisited.

The price paid to ensure that adequate power is provided is substantial. Each option requires the use of a Sol Ark 5K-1P inverter/charge controller. This works in conjunction with the battery bank of eight 210 amp hour AGM batteries, which will then run the fan. This is necessary for the generator to reduce the number of start/stop cycles. The cost of the inverter and battery system is \$13,150. The additional cost of the generator and/or the solar array is \$5,410 and \$15,570 respectively.

## II. *Temperature DAQ*

### II.I. *Motivation*

A temperature DAQ was developed for the inside of the mine. The purpose of this system was twofold. First and foremost it was to inform a controller when it needs to turn on the cool mine. Secondly, it can operate as a backup data collection source to inform researchers about the temperature distribution within the mine. The temperature DAQ was designed to cover the entire 900 ft of the main shaft to monitor both the experimental area (which would influence the controller) and the control area (which would not influence the controller and not be cooled). To do this a sensor harness was developed that would power different sensor nodes along the mine shaft and return information back to the main hub.

### II.II. *Temperature Sensor Selections*

The Dwyer 0-4 Series Resistance Temperature Detector (RTD) sensor was initially chosen for use with the Temperature DAQ. This model was selected for its environmental rating of IP66 and stated temperature tolerances. Qualification testing was then done on a randomly selected unit to ensure the temperature sensor's accuracy was as stated. This testing was performed in an ESPEC Environmental Chamber. The sensor was brought through the expected operating range, 0°C to 10°C, in 1°C increments

as well as 20°C, the measured resistance was then compared to the expected resistance at that temperature, and the percent error was calculated. The data collected is shown below.

| Dwyer Qualification Data |                 |          |         |
|--------------------------|-----------------|----------|---------|
| Temperature [°C]         | Resistance [kΩ] |          | % Error |
|                          | Observed        | Expected |         |
| 0                        | 1.004           | 1.0000   | 0.40%   |
| 1                        | 1.007           | 1.0039   | 0.31%   |
| 2                        | 1.010           | 1.0078   | 0.22%   |
| 3                        | 1.015           | 1.0117   | 0.33%   |
| 4                        | 1.017           | 1.0156   | 0.14%   |
| 5                        | 1.022           | 1.0195   | 0.25%   |
| 6                        | 1.025           | 1.0234   | 0.16%   |
| 7                        | 1.029           | 1.0273   | 0.17%   |
| 8                        | 1.034           | 1.0312   | 0.27%   |
| 9                        | 1.037           | 1.0351   | 0.18%   |
| 10                       | 1.041           | 1.0390   | 0.19%   |
| 20                       | 1.067           | 1.0779   | 1.01%   |

Table 1: Dwyer Qualification Data

The greatest percent error was outside of the expected operating range, and very small (1.01%), thus the sensor was deemed acceptable by the OSHE project team.

This experiment also allowed for the creation of a calibration curve that would allow for the calculation of temperature based on the resistance. Generally these curves are a nonlinear second order quadratic, but in this specific case, it was found that a linear regression was more accurate [1]. The root mean square error for a linear model based on the experimental data was 1.9251, while the second order model was 862.2553]. The linear equation used to calculate temperature is shown in Equation 1.

$$T = 3.2664R + 1,005.2516 \quad (1)$$

### II.III. PCB Design

An RTD measures temperature through a change in resistance. This means that the lead resistance of the RTD connection can highly influence how the measured temperature is calculated. This led to two problems for measuring temperature in the hibernacula. First, the runs are high distance so a large lead resistance would have to be included. Another issue is the increased risk of signal degradation. The second issue is the nonconstant lead length. This would mean that each sensor node would have to be individually designed for. Because of these problems, serialization made sense to implement. There are several different serialization communication protocols, but most of them are not designed for high-distance runs. Two candidates were considered based on this distance consideration: CAN and EtherNet. Between the two CAN was selected because it was considered to be simpler and lower cost.

To implement CAN, a serialization PCB would need to be designed. This PCB would have to a) take an accurate temperature measurement, b) serialize this temperature measurement, and then c) transmit the measurement on the CAN bus. Two other considerations for the PCB are that it would have to be relatively low power due to being off the grid and be able to be turnkey manufactured by non-technical professionals. The PCB would also need to fit in the O-4 temperature sensor box so it could be protected from the elements.

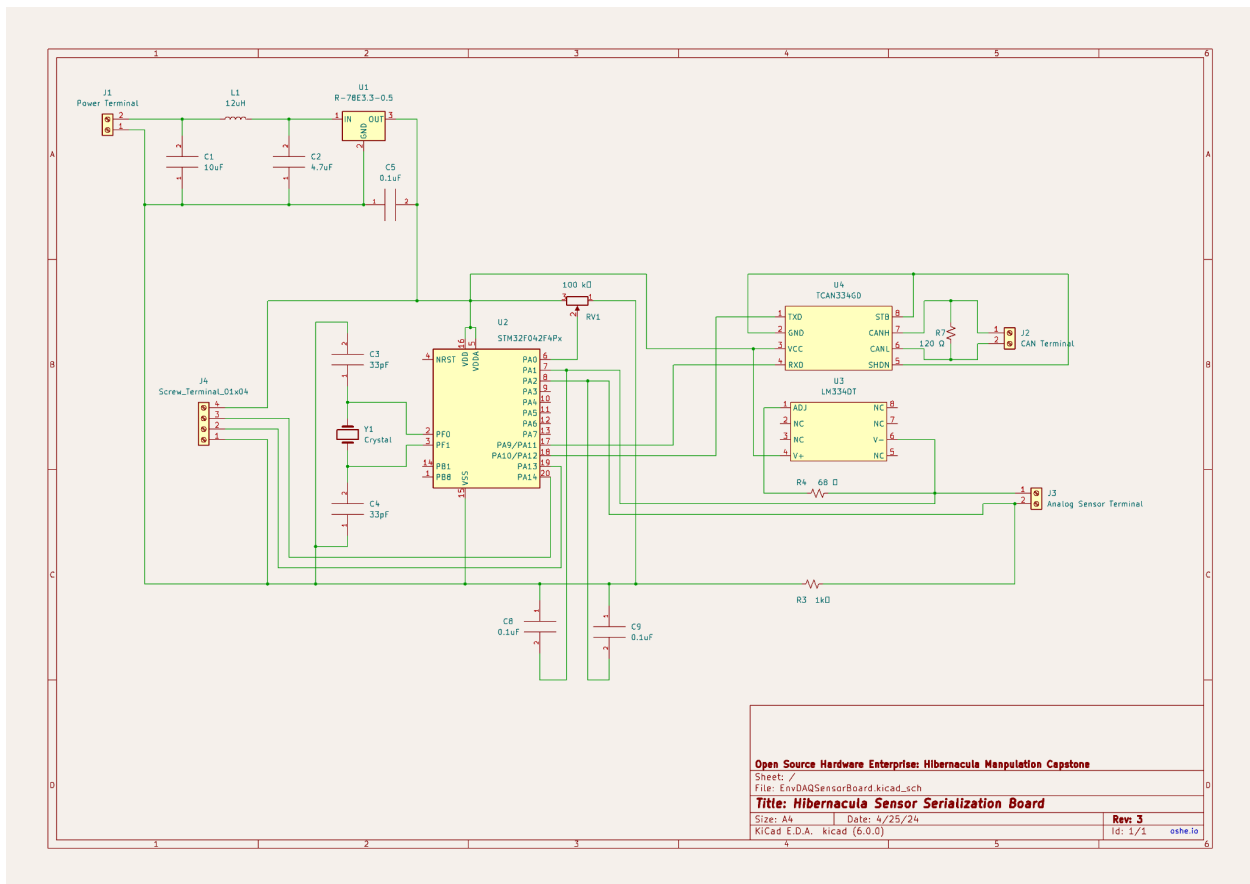


Figure 7: Temperature DAQ Schematic

The schematic shown in Figure 7 is the final schematic for serializing the temperature data. The PCB can be roughly split into three parts: a power stage, a measurement circuit, and a serialization circuit. The power stage was designed to take a 12V input and step the voltage down to 3.3V. The voltage supply of the sensor harness was selected at 12V to reduce line losses and because it is already used in the cooling system. The R-78E3.3-0.5 buck converter was selected because the only peripherals needed were an input and output filter, its 90% efficiency rating at 12V, and it met the necessary size constraints. The input and output filters were designed based on the datasheet.

The measurement circuit was based on a TI Application Note [1]. The Dwyer RTD is a two-wire RTD and therefore the Two-Wire RTD Measurement with Low Side Reference was used in the PCB design [1]. The LM334DT was used to create the necessary constant current source. One issue with constant current sources is that they are highly influenced by temperature. The LM334DT datasheet provided a calculation for current based on temperature which is taken into account in the coding of the temperature calculations. The peripherals for the constant current source were selected so that it is producing around 1mA (will drift depending on temperature).

The final section of the PCB is the serialization circuit. The STM32F042F4P6 was selected for a few reasons. First, a microcontroller was considered instead of just a CAN controller because it had an onboard ADC and it allowed for filtering options. ADCs that input analog voltage and output CAN were unavailable or unable to be found. The STM32 was specifically picked because it had CAN, a 12-bit ADC, and wake-up on CAN capabilities. Another reason is that it uses ARM programming which we are familiar with and the package was the one we felt most comfortable in being able to work with. To pair with the STM32, a TCAN334GD was selected as the CAN transceiver because of its wake-up on CAN capabilities. An external oscillator had to also be added to the design because the STM32 internal clock drift is above the requirement for CAN at low temperatures. The final part of the serialization is a potentiometer which is used to a unique address to CAN node.

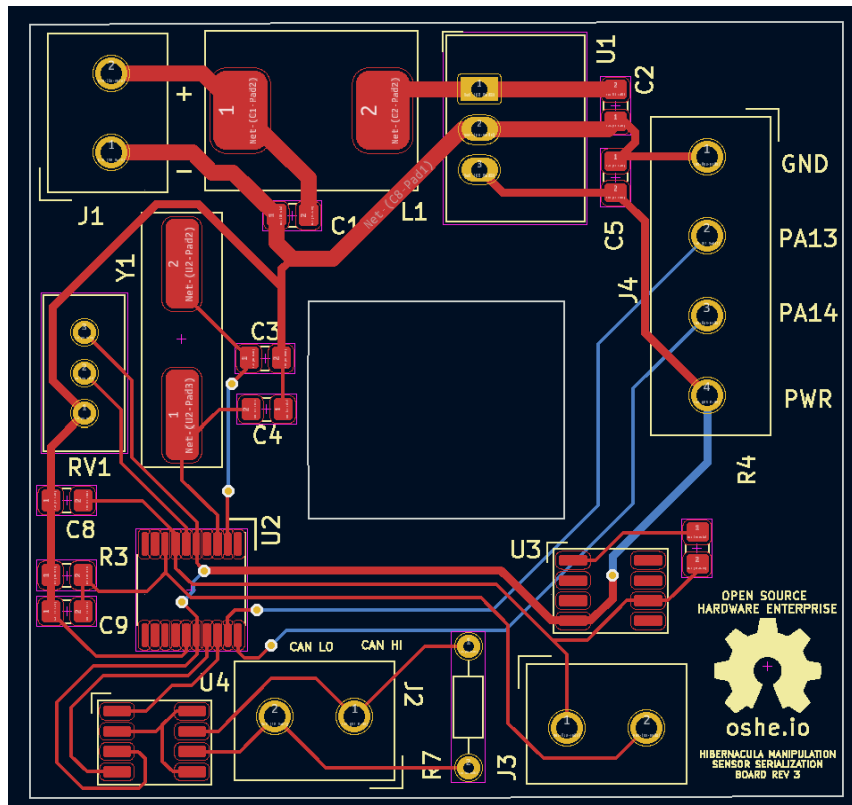


Figure 8: Temperature DAQ Board File

The final board file is shown above in Figure 8. The board was designed in a way to minimize parasitics and to stay within the size constraints. The physical strain on the wire inputted into the PCB was also considered in this design. The board is undersized to allow for softer wire bends. Finally it was designed to fit tight with the center connector to properly seat the board inside the enclosure.

#### *II.IV. Wire Selection*

The wire for the Temperature DAQ must be able to carry a minimum of 12 volts and 7 amps over 900 feet. The cable will be spliced every 50 feet, and signal degradation must be minimized to ensure the accuracy of the temperature measurements. The cable will be exposed and potentially be run on the ground, thus an Exposed Run (ER) rating is required. Two main options were presented regarding the wire to fulfill these requirements:

1. Power over Ethernet (POE) Cable
2. Cable specified with the help of the International Wire and Cable Company (IWC)

While POE would have been much less expensive (\$500) than the cable quoted by IWC (\$2890), the POE would have likely required repeaters and boosters to maintain signal integrity. The cable provided by IWC would be able to maintain signal integrity without repeaters or boosters and would be easy for future project work to expand on, as the cable is much easier to work with. IWC quoted two separate cables for this application, one for data transmission and one for power. Both cables are 2-pair, and only 1-pair is required. This allows for future expansion if wanted and provides security in the event of a potentially compromised pair. The data cable is twisted and shielded, so signal degradation is unlikely. The OSHE project team made the decision to move forward with the IWC cable due to the higher confidence of the cable. This project team will not be around when the system is used, so it is critical that it works. The POE cable introduces too many unknowns to be confident in it at this time, and not enough time is left in the semester to research and test it.

#### *II.V. HMI*



Figure 9: HMI Physical Design



The figure above shows the HMI (Human Machine Interface). This box contains the Raspberry Pi, buck converter, and Can Pal underneath the custom 3D-printed insert. This interface will allow the user to set the desired temperature of the system by using the keypad. The temperatures will be shown on the LCD. The LED is there to indicate the system is working, so the user can easily see if any problems are occurring. Finally, the switch is there to power the system on and off.

The 3D-printed insert is simply placed inside the box, with there being space underneath for the electrical components to fit. To print the 3D-printed insert, the recommended infill is 15-20%. It is also recommended to ensure a big enough printer is used so it can be printed in one piece; most standard-size 3D printers will work (for example, the Ender 3). The design file was made parametrically, meaning it can easily be changed if the user wants to use different parts, but it is recommended to use the parts included in the BOM in this report.



Figure 10: Wire Egress

The above figure shows where the wires will be going into/out of the box. The entire box is IP67 rated, but drilling the hole for the wires compromises that IP rating. It is recommended once the wires are all connected to caulk around the wires to ensure no water enters the HMI.

## II.VI. Code

The HMI and the temperature DAQs were controlled using a Raspberry Pi zero with an RS485 CAN hat. The Raspberry Pi was chosen for its simple CAN integration and programmability. All of the code for the HMI control and CAN regulation was written in Python which has wide access to open source libraries. Open-source libraries were used for the LCD and CAN control. The Temperature DAQs were programmed in C and extensive use was made of the STM32CubeIDE which included native support for our selected chip. Flashing the STM32 microcontroller was an early issue as the initial theory of programmability through UART proved incorrect. This was solved with the procurement of an STMicroelectronics STLINK-V3SET, a modular debugging and programming tool specifically designed for STM32 microcontrollers. This allowed us to easily program and debug our chip using the four-pin Serial Wire Debugger.

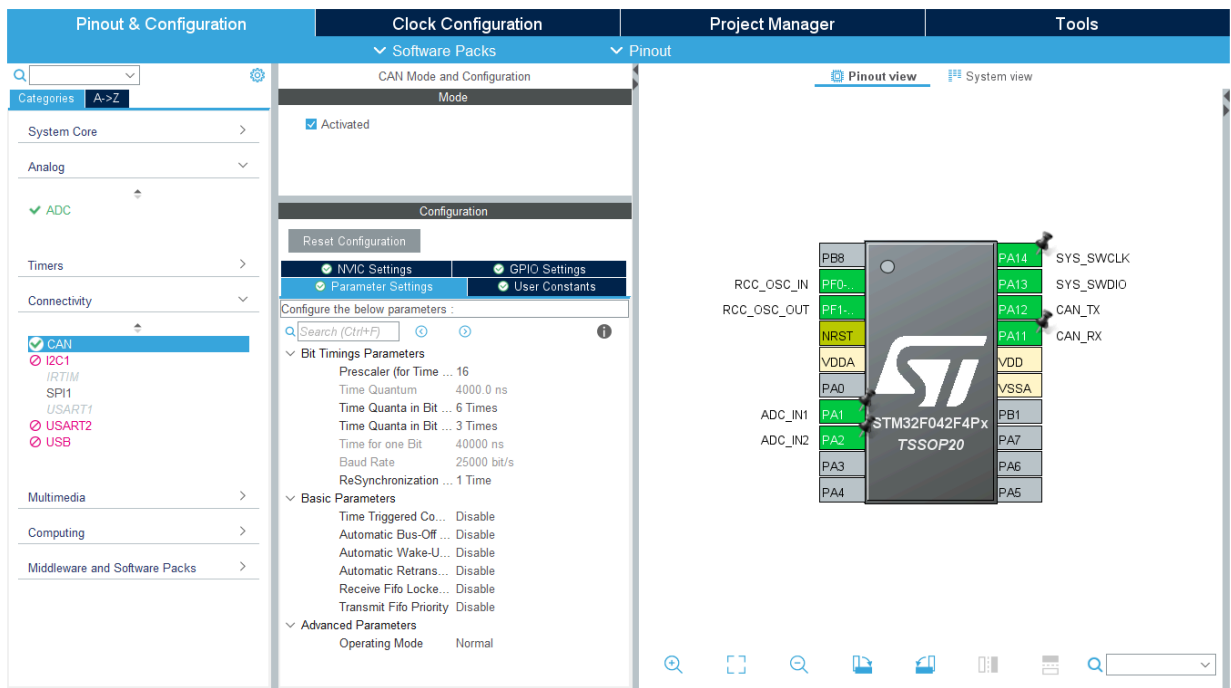


Figure 11: STM32CubeIDE Viewer

Figure 11 is an example of the utility provided by the STM32CubeIDE. The software offered a visual representation of our microcontroller and easy pin assignments. Setting up the CAN, ADC, and clock functionality was done in this stage of the programming workflow as the software provided skeleton functions based on the selected parameters. The IDE also included native programming and debugging with the use of the STLINK device meaning code could be debugged while running on our DAQ. Code was written to handle ADC calculations and send the calculations over the CAN bus. ADC values are taken in sets of ten and averaged before being sent to the Pi every ten minutes.

The Pi receives the CAN messages from each node and sends them through control logic to determine whether or not the cooling system should run. The Pi displays the temperature at each node on an LCD and accepts target temperature input using a 4x4 keypad. The control logic accounts for heating and cooling based on the current target temperature. The target temperature can be reconfigured depending on

whether an individual node or average calculation over many nodes is used to define it. This functionality helps set up controlled experiments and well-defined microclimates.

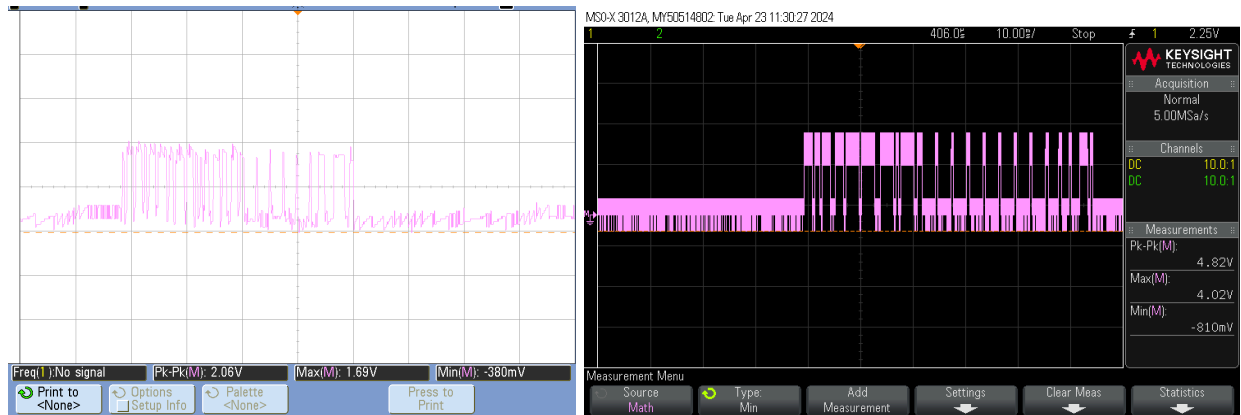


Figure 12: CAN Bus Output

During the coding process, an issue was discovered involving the internal clock of the STM32 microcontroller. The clock was unable to consistently drive the CAN communication due to a low overall accuracy. Low baud rates allowed for a few frames of data to be sent before the clock fell out of sync and data transmission stopped. A crystal oscillator was added to provide a more stable clock at all temperatures. Figure 12 depicts the difference between the CAN bus using the volatile internal clock (left) and the consistent external oscillator (right).

### III. Air Flow Simulation and Calculations

For the simulations, the following statements were considered factual. The source of the information is called out in parentheses. Professor Nathan Manser of the Geological and Mining Engineering and Sciences Department advised simulation efforts.

1. The experimental area is cylindrical
  - a. The experimental area is 400 feet long (MDNR)
  - b. The experimental area has a cross-sectional area of 50.9 square feet (see below)
2. The experimental area is completely sealed (for calculation purposes)
3. The initial temperature within the mine is 7°C (MDNR)
4. The target temperature within the mine is 4°C (MDNR)
  - a. The target temperature shall be reached in one week (OSHE Team)
5. The temperature of the outside air is 4°C (see below)
6. The mine walls do not warm the air (for calculation purposes)
7. Adequate ductwork is installed in conjunction with the fan (for calculation purposes)
8. The temperature of the mine needs to reach 4°C in 1 week or 168 hours (MDNR)

Statement 1b was calculated using the point cloud that the Douglass Houghton Student Chapter of the National Society of Professional Surveyors collected on 11/09/2023. A typical cross-section of the mine is shown below. This particular cross-section had an area of 48.9 square feet. The cross-sectional area of the shaft was determined every 50' from the beginning of the experimental area until a distance of 800' was

reached. Averaging these samples (shown in Table 2) yielded an average cross-sectional area of 46.4 feet squared. This value was rounded to 50 feet squared for the simulation.

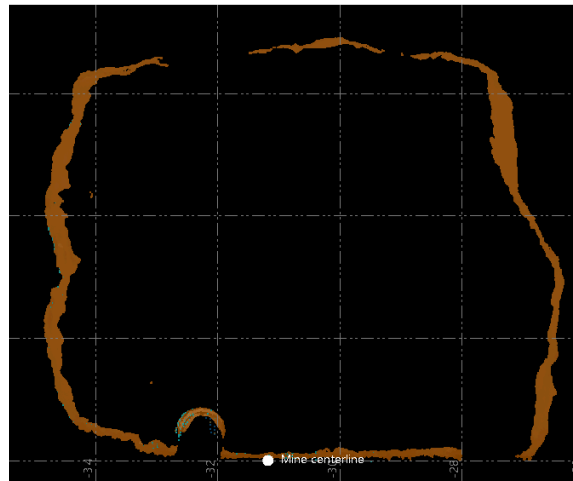


Figure 13: Sample Cross-section of the Mine

| Cross-sectional Area of Shaft Every 50 Feet |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |      |
|---|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| Station ID                                  | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   | 13   | 14   | 15   | 16   |
| Area [ft <sup>2</sup> ]                     | 59.5 | 54.6 | 47.5 | 46.1 | 42.3 | 51.3 | 50.7 | 47.4 | 47.5 | 41.7 | 45.9 | 42.9 | 40.5 | 36.5 | 46.7 | 40.7 |

Table 2: Cross-sectional Area Data

Statement 5 states that the outside air is 4°C. This was used as a conservative estimate of the system; in reality, data from [U.S Climate Data](#) shows the average temperature in Ontonagan during the months of operation (Oct-Mar) is -2.4°C. This colder temperature will decrease the time and volume of air needed to cool the experimental area.

|              | Jan   | Feb   | Mar  | Apr  | May  | Jun  | Jul  | Aug  | Sep  | Oct  | Nov  | Dec   |
|--------------|-------|-------|------|------|------|------|------|------|------|------|------|-------|
| °C - High    | -3.9  | -1.1  | 4.4  | 11.7 | 19.4 | 23.9 | 26.1 | 25.6 | 21.1 | 13.3 | 5.0  | -1.7  |
| °C - Low     | -13.3 | -12.8 | -7.8 | -1.1 | 4.4  | 10.0 | 12.8 | 12.2 | 8.3  | 2.8  | -3.3 | -10.0 |
| Average (°C) | -2.4  |       |      |      |      |      |      |      |      |      |      |       |

Table 3: Average Temperature in Ontonagon, MI

The following information was used in the cooling simulation to determine the time it would take for six different fans (three theoretical and three real) running continuously to bring the mine from 7.5°C to 4°C.

1. The fan flow rate is manufacturer-specified.
2. The air density is a known number that is a function of the air temperature.
3. Pounds of Outside Air per Hour is a function of the air density and fan cfm.
4. The Hibernacula cross-sectional area and length were determined above. The Hibernacula volume is a function of these
5. The duct diameter is specified by the manufacturer.
6. The duct friction factor is a known value based on the type of ductwork used.

7. The duct air power required is calculated using the duct friction factor, perimeter, and cross-sectional area. This is the power needed to overcome the friction of the duct.

|                                  |             |           |             |            |           |           |
|----------------------------------|-------------|-----------|-------------|------------|-----------|-----------|
| Fan Flowrate [cfm]               | 1           | 5         | 10          | 570        | 1394      | 2850      |
| Temp Outside [C]                 | 4           |           |             |            |           |           |
| Temp Inside [C]                  | 7           |           |             |            |           |           |
| Outside Air Density [lb/ft3]     | 0.079       |           |             |            |           |           |
| Hibernacula Air Density [lb/ft3] | 0.078       |           |             |            |           |           |
| Pounds of Outside Air per Hour   | 4.74        | 23.7      | 47.4        | 2701.8     | 6607.56   | 13509     |
| Hibernacula X-area [ft2]         | 50          |           |             |            |           |           |
| Hibernacula Length [ft]          | 400         |           |             |            |           |           |
| Hibernacula Volume               | 20000       |           |             |            |           |           |
| Pounds of Air in Hibernacula     | 1560        |           |             |            |           |           |
| Duct Diameter [ft]               | 1           |           |             | 0.75       | 1         | 1.5       |
| Duct X-area [ft2]                | 0.785375    |           |             | 0.44       | 0.79      | 1.77      |
| Duct Perimeter [ft]              | 3.1415      |           |             | 2.356125   | 3.1415    | 4.71225   |
| Duct Friction Factor             | 0.000000003 |           |             |            |           |           |
| Duct Friction Head [in H2O]      | 9E-07       | 2.308E-05 | 9.23077E-05 | 0.39987692 | 1.7937563 | 4.9984615 |
| Duct Air Power Required [Watts]  | 9.2E-07     | 1.2E-04   | 9.2E-04     | 2.3E+02    | 2.5E+03   | 1.4E+04   |

Table 4: Excel Simulation Variables

The graph below visualizes the effects on temperature the respective fans have on the mine temperature. The three hypothetical fans (1, 5, and 10 CFM) were unable to achieve 4°C in one week thus the data was omitted from the graph.

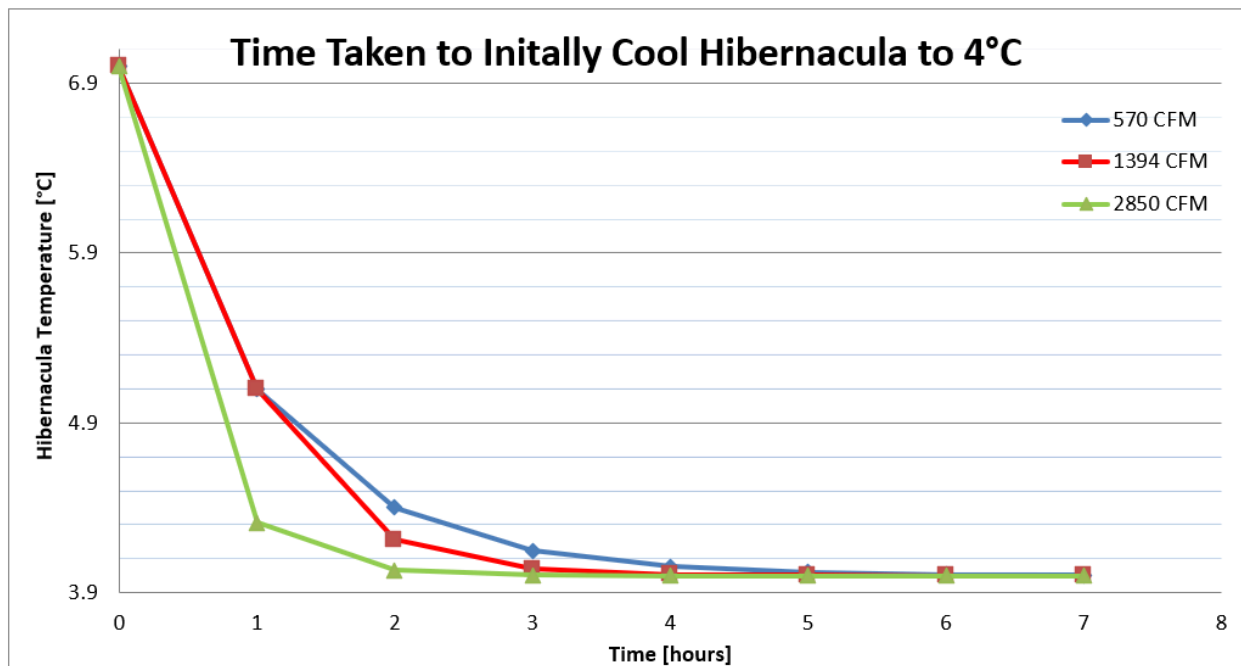


Figure 14: Excel Simulation Results

The table below shows the time in which each fan size achieved 4°C. The “Adjusted Time” Table below adjusts for inaccuracies in our model, such as no heat from the mine walls and the experimental area not being completely sealed.

| <b>Time to Achieve 4°C</b> |                   |                            |
|----------------------------|-------------------|----------------------------|
| <b>Fan [CFM]</b>           | <b>Time [hrs]</b> | <b>Adjusted Time [hrs]</b> |
| 570                        | 7                 | 14                         |
| 1394                       | 6                 | 12                         |
| 2850                       | 5                 | 10                         |

Table 5: Time to Reach 4°C from Excel Simulation

This data suggests that a 570 CFM fan can very likely cool the experimental area to 4°C within a week. Even when applying a 200% time buffer to compensate for the assumptions made in the simulation, the fan still achieved 4°C in well under a week. With this information, the OSHE project team feels confident about moving forward with the Allegro Industries Conf. Sp Fan, Axial, 1/4 HP Part# 9536 that the MDNR has on-site.

#### *IV. Control System*

The controller proposed for this system was a simple relay control system. The initial specs to meet were an overshoot of less than 12.5% (within .5C of target) and a rise time of 1 week. Ideally it would also have zero steady state error but this is not possible with a relay controller. As a proof of concept a model of the controller was tested in Simulink. To properly test the controller a plant model would have to be constructed. The plant of the mine was modeled in two parts. The first part was the effect of the fan cooling. This was done using the model from section III. The equation for this is shown in Equation 2.

$$T_o(k + 1) = \frac{(T_o(k)*R_o*t) + (T_i(k)*A_i)}{(R_o*t + A_i)} \quad (2)$$

where  $T_o$  is the temperature outside of the cave (C),  $R_o$  is the rate at which air is being pumped into the cave from outside (lb/min),  $t$  is sample period (min),  $T_i$  is temperature inside the cave (C), and  $A_o$  is the amount of air in the cave (lb). This is making the assumption that the air is at constant density, which is not true at large temperature ranges, but should hold roughly true for the narrow range present in the cave.

The second half of the plant design is the effect of the cave walls raising the air temperature of the cave. The equations for the cave heating were developed from results taken from the Carlsbad Cavern [2]. While there are some differences between the Mead Mine and the Carlsbad Cavern, namely size and rock type (the Mead Mine is mostly surrounded by basalt and Carlsbad Cavern is a dolomite and limestone cave), it is a good estimate. The equation developed is shown in Equation 3 below.

$$\Delta T(k) = \frac{hA(T_c - T_i(k))t}{mC} \quad (3)$$

where  $\Delta T$  is the change in temperature from cave walls,  $h$  is the heating coefficient,  $A$  is a surface area of the cave,  $T_c$  is the cave wall temperature,  $T_i$  is the air temperature in the cave,  $t$  is the sampling time,  $m$  is mass of the air, and  $C$  is the specific heat. The values for  $h$  and  $C$  are based on the Carlsbad Cavern paper [2].  $A$  and  $T_c$  are constants taken from the surveying results and the DNR respectively.  $t$  was selected to be 10 minutes. This left  $\Delta T$  completely based on  $T_i$ , with the final equation being:

$$\Delta T(k) = 0.14145 - 0.0202072T_i(k) \quad (4)$$

Based on these equations the plant model was built in the Simulink. The controller is a simple relay block with a switch block that checks to make sure that the outside temperature is colder than the temperature inside the cave. For this simulation a constant outside temperature was used to keep the model simple. An attempt was made to use the February weather data from the Porcupine mountains, but Simulink did not work well with the imported time series. An image of the model is shown in Figure 15.

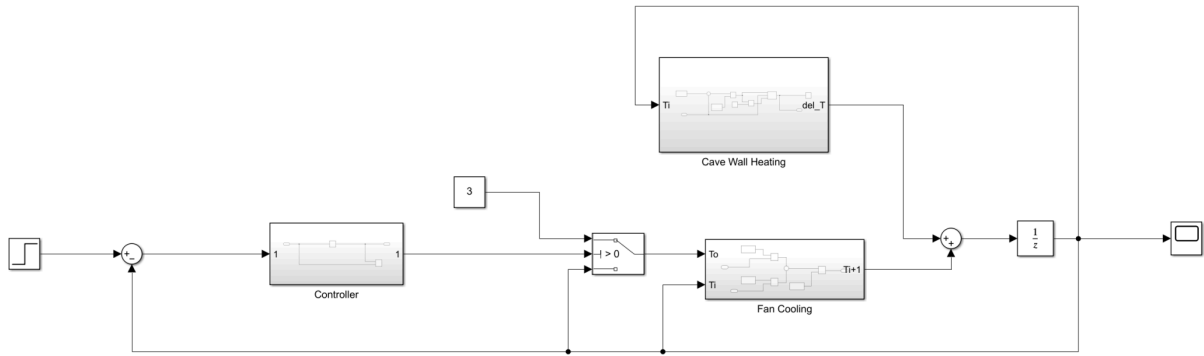


Figure 15: Simulink model used to simulate controller

The results are shown below in Figure 16. The results show that the controller is within rise time and overshoot spec. It is actually significantly quicker than expected. The ripple around the setpoint is at 0.1 C which is also within specs.

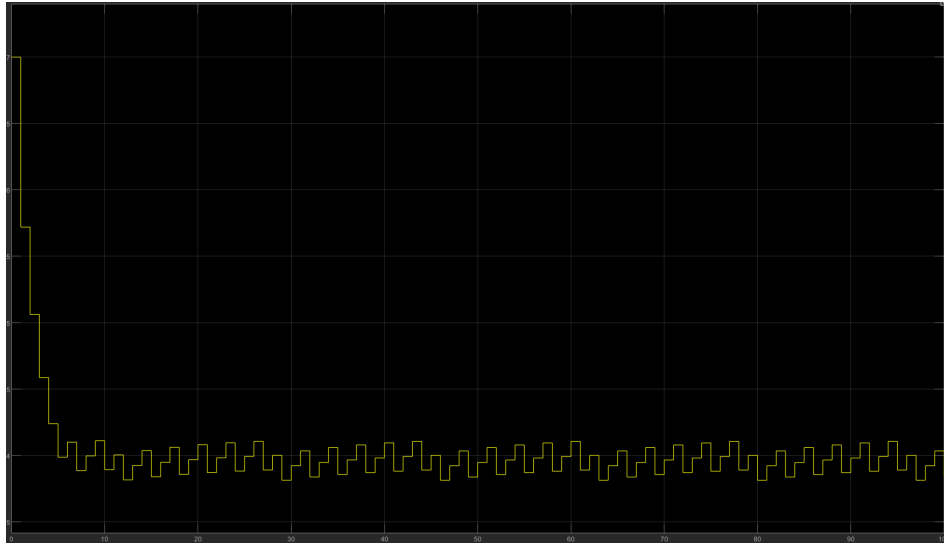


Figure 16: Control System Results

## Implementation and Integration:

With each component of the project being worked on by a different team member, time was taken towards the end of the year to integrate each component into a final system. The first-generation temperature DAQs were constructed and implemented into the control system and HMI consisting of the Raspberry Pi Zero, LCD, and keypad. With the system put together, testing was done to ensure a 12V power supply could safely power all components. Code was written to control the future fan system and a final system construction plan was developed.

## Final Comments:

The project at the end of the year is fully designed. There may be a few parts that could be redesigned to be better, but the design would be completely operational in the field. Some of the practical implementation details are a little fuzzy (e.g. how the DNR wants to hang the harness), but overall almost everything is taken into account. Unfortunately due to timing and supply chain issues the project was not able to be fully assembled and installed, but most, if not all of the engineering leg work is complete.



## BOM

| Part Name  | Quantity | Cost Per | Total Cost |
|--|----------|----------|------------|
| <b>DAQ - Temperature</b>   |          |          |            |
| <a href="#">Raspberry Pi Zero (with Headers)</a>                                 | 2        | \$8.00   | \$16.00    |
| <a href="#">RS485 CAN HAT for Raspberry Pi</a>                                   | 2        | \$15.59  | \$31.18    |
| <a href="#">3.3-V CAN Transceiver</a>  | 4        | \$3.37   | \$13.48    |
| <a href="#">Adafruit CAN Pal</a>   | 2        | \$3.95   | \$7.90     |
| <a href="#">ARM®-based 32-bit MCU w/ CAN and I2C</a>                             | 4        | \$3.08   | \$12.32    |
| <a href="#">16 GB SD Card with Buster Lite</a>                                   | 2        | \$4.98   | \$9.95     |
| <a href="#">5V 2.5A Switching Power Supply with 20AWG MicroUSB Cable</a>         | 1        | \$8.25   | \$8.25     |
| <a href="#">USB OTG Host Cable - MicroB OTG male to A female</a>                 | 2        | \$2.50   | \$5.00     |
| <a href="#">4.5-V to 17-V Input, 2-A Synchronous Step-Down Voltage Regulator</a> | 4        | \$0.39   | \$1.56     |
| <a href="#">Input Voltage 3.5 V to 36 V Step-Down Switching Regulator</a>        | 2        | \$2.36   | \$4.72     |
| <a href="#">Series O-4 Outside Air Temperature Sensor (1 O-4 RTD and 1 O-4E)</a> | 2        | \$18.00  | \$36.00    |
| <a href="#">SHT-30 Mesh-protected Weather-proof Temperature/Humidity Sensor</a>  | 1        | \$24.95  | \$24.95    |
| <a href="#">Step Down Converter, 5V 5A Output, 3.3v-36V Output</a>               | 2        | \$8.50   | \$17.00    |
| <a href="#">20AWG, 6 Color Hookup Wire</a>                                       | 1        | \$23.99  | \$23.99    |
| <a href="#">3.3 uH Inductor</a>  | 4        | \$0.42   | \$1.68     |
| <a href="#">Constant Current Source - 10mA</a>                                   | 4        | \$1.59   | \$6.36     |
| Custom PCB Boards Rev 1  | 1        | \$24.17  | \$24.17    |
| <a href="#">10 uF Capacitor</a>  | 12       | \$0.17   | \$2.04     |
| <a href="#">0.1 uF Capacitor</a>   | 50       | \$0.08   | \$3.87     |
| <a href="#">4.7 uF Capacitor</a>   | 12       | \$0.23   | \$2.76     |
| <a href="#">12 uH Choke</a>  | 12       | \$0.42   | \$5.04     |
| <a href="#">68 Ω Resistor</a>  | 12       | \$0.13   | \$1.56     |

|  |       |         |           |
|--|-------|---------|-----------|
| <a href="#">120 <math>\Omega</math> Resistor</a>       | 12    | \$0.10  | \$1.20    |
| <a href="#">1k <math>\Omega</math> Resistor</a>        | 12    | \$0.19  | \$2.28    |
| <a href="#">100k <math>\Omega</math> Potentiometer</a> | 12    | \$1.77  | \$21.24   |
| <a href="#">Step-Down Voltage Regulator</a>            | 12    | \$3.25  | \$39.00   |
| <a href="#">ARM®-based 32-bit MCU w/ CAN and I2C</a>   | 12    | \$2.94  | \$35.28   |
| <a href="#">Adjustable Constant Current Source</a>     | 12    | \$1.59  | \$19.08   |
| <a href="#">3.3-V CAN Transceiver</a>                  | 12    | \$3.37  | \$40.44   |
| <a href="#">Two Connection Screw Terminal</a>          | 36    | \$0.36  | \$13.07   |
| <a href="#">Four Connection Screw Terminal</a>         | 12    | \$0.67  | \$8.06    |
| Custom Cable   | 2000' | NA      | \$2890.00 |
| <a href="#">1k <math>\Omega</math> RTD</a>             | 12    | \$18.55 | \$222.60  |
| <a href="#">10 uF Capacitor</a>                        | 20    | \$0.17  | \$3.40    |
| <a href="#">0.1 uF Capacitor</a>                       | 60    | \$0.08  | \$4.80    |
| <a href="#">4.7 uF Capacitor</a>                       | 20    | \$0.23  | \$4.60    |
| <a href="#">12 uH Choke</a>                            | 20    | \$0.42  | \$8.40    |
| <a href="#">68 <math>\Omega</math> Resistor</a>        | 20    | \$0.10  | \$2.00    |
| <a href="#">120 <math>\Omega</math> Resistor</a>       | 20    | \$0.10  | \$2.00    |
| <a href="#">1k <math>\Omega</math> Resistor</a>        | 20    | \$0.19  | \$3.80    |
| <a href="#">100k <math>\Omega</math> Potentiometer</a> | 20    | \$1.77  | \$35.40   |
| <a href="#">Step-Down Voltage Regulator</a>            | 20    | \$3.25  | \$65.00   |
| <a href="#">ARM®-based 32-bit MCU w/ CAN and I2C</a>   | 20    | \$2.94  | \$58.80   |
| <a href="#">Adjustable Constant Current Source</a>     | 20    | \$1.59  | \$31.80   |
| <a href="#">3.3-V CAN Transceiver</a>                  | 20    | \$3.37  | \$67.40   |
| <a href="#">Two Connection Screw Terminal</a>          | 20    | \$0.36  | \$7.20    |
| <a href="#">Four Connection Screw Terminal</a>         | 20    | \$0.67  | \$13.40   |
| Custom PCB Boards Rev 2                                | -     | -       | \$86.76   |
| Custom PCB Boards Rev 2 Backups                        | -     | -       | \$40.27   |

|   |    |          |           |
|---|----|----------|-----------|
| DAQ - Temperature Total   |    |          | \$3898.55 |
| <b>Power Generation</b>   |    |          |           |
| <a href="#">100 Watt Amorphous Solar Panel Kit</a>  | 1  | \$179.99 | \$179.99  |
| 10x3.5 Wood Screws  | 1  | \$14.49  | \$14.49   |
| Cable Ties 24"  | 1  | \$7.99   | \$7.99    |
| 2x4x8   | 2  | \$7.59   | \$15.18   |
| 4x4x8   | 2  | \$49.99  | \$99.98   |
| Power Generation Total  |    |          | \$317.63  |
| <b>DAQ - Power</b>  |    |          |           |
| <a href="#">1kΩ 25W Resistor</a>  | 10 | \$1.11   | \$11.10   |
| <a href="#">3.9kΩ 25W Resistor</a>  | 10 | \$1.11   | \$11.10   |
| <a href="#">Sunflower Solar Power Manager</a>   | 3  | \$38.90  | \$116.70  |
| <a href="#">3.7V 1500mAH Lipo</a>   | 6  | \$16.00  | \$96.00   |
| <a href="#">Hall Effect 5V Current Sensor</a>   | 5  | \$4.36   | \$21.80   |
| <a href="#">8SOIC Breakout boards</a>   | 5  | \$2.95   | \$14.75   |
| <a href="#">Arduino Nano</a>  | 3  | \$18.95  | \$56.85   |
| <a href="#">SAE Connector Cable SAE Connector Plug 2 Pin (3-Pack)</a>   | 2  | \$11.99  | \$23.98   |
| <a href="#">LeMotech Junction Box with Reserved Holes ABS Plastic Electrical Box IP65 Waterproof Dustproof Project Enclosure for Electronics White 7.9 x 7.9 x 3.1 inch</a> | 6  | \$20.99  | \$125.94  |
| <a href="#">Push Buttons</a>  | 10 | \$0.94   | \$9.40    |
| <a href="#">36-PIN 0.1 FEMALE HEADER (5 Pack)</a>   | 4  | \$2.95   | \$11.80   |
| <a href="#">SD Card Adapter Module</a>  | 1  | \$6.99   | \$6.99    |
| <a href="#">32GB SD Cards</a>   | 1  | \$20.99  | \$20.99   |
| Roofing Screws  | 1  | \$12.99  | \$12.99   |
| Silicon Caulk   | 1  | \$9.99   | \$9.99    |
| Caulk Gun   | 1  | \$9.99   | \$9.99    |
| Spray Paint   | 1  | \$13.00  | \$13.00   |

|                     |   |        |           |
|---------------------|---|--------|-----------|
| 32GB MicroSD Cards  | 3 | \$7.88 | \$23.64   |
| DAQ - Power Total:  |   |        | \$597.01  |
| Total Project Cost: |   |        | \$4367.90 |

## References

- [1] J. Wu, "A Basic Guide to RTD Measurements." Texas Instruments Incorporated, Mar. 2023
- [2] S. Shindo, "MICROMETEOROLOGICAL MODELING OF AN IDEALIZED CAVE AND APPLICATION TO CARLSBAD CAVERN, NM," New Mexico Institute of Mining and Technology, Socorro

# Appendix

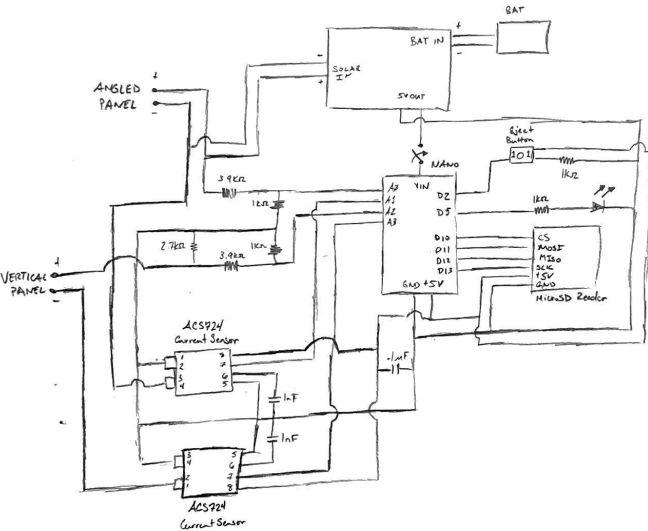


Figure 17: Power DAQ Schematic

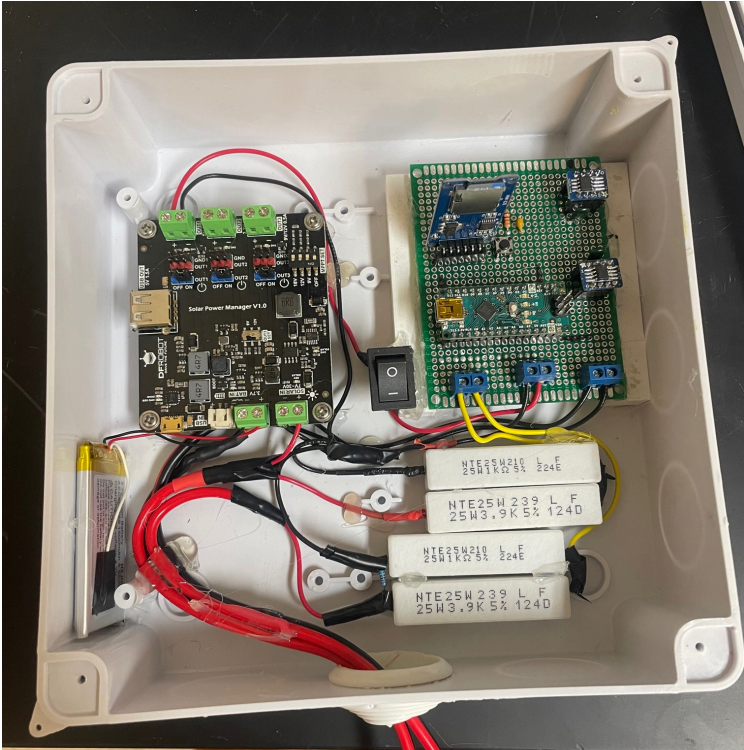


Figure 18: Power DAQ Implementation